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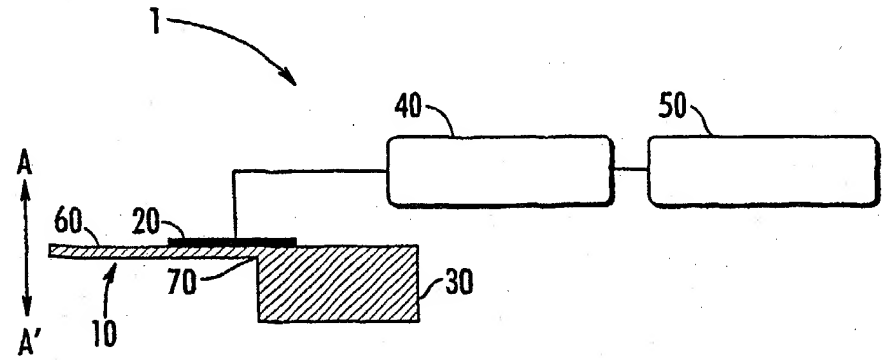
(54) Title: PIEZOELECTRIC POWER GENERATOR



(57) Abstract: A sustained power generator (1) comprising a micro-fabricated suspended mass or a cantilever (10) and a piezoelectric material (20) in communication with the cantilever wherein a vibration of the cantilever causes stresses in the piezoelectric material, thus generating a current. And a method for providing a sustained power generator (1) comprising the steps of providing a silicon micro-fabricated cantilever means (10), integral with base (30) the cantilever means having a free end (60) and a secured end (70); placing a piezoelectric material in communication with the secured end of the cantilever; providing an external acceleration for vibrating the free end such that a current is generated in the material in response to the external acceleration vibrating the free end; and providing a storage device (50) with optional rectification means (40) in communication with the piezoeletric material for

WO 01/20760 A1

TITLE OF THE INVENTION
PIEZOELECTRIC POWER GENERATOR

STATEMENT OF GOVERNMENT RIGHTS

The U.S. Government has rights in this invention pursuant to Contract Number DE-AC05-00OR22725 between the U.S. Department of Energy and UT-Battelle, LLC.

FIELD OF THE INVENTION

The present invention relates generally to power generation. Specifically, the present invention relates to an alternate means for generating power.

BACKGROUND OF THE INVENTION

There have been several attempts to provide power generators in the art. For instance, U.S. Patent No. 4,952,836 to *Robertson* teaches a piezoelectro-static generator wherein an internal electric potential is induced by bending strips of material exhibiting the piezoelectric effect. *Robertson* teaches that the material is arranged radially about an axis to provide an annual stator for converting mechanical motion along the axis to corresponding electric potential, i.e., high currents and high voltages for a variety of applications.

U.S. Patent No. 5,751,091 to *Takahashi, et al.* teach a power generator which generates electric power upon application of a strain. The *Takahashi, et al.* generator includes a vibrating arm having at least two piezoelectric portions with a support layer therebetween, the arm being capable of outputting an alternating current through electrodes. A rectifying device may be connected to the generator, as well as a condensing device for accumulating the rectified current.

U.S. Patent No. 5,703,295 to *Ishida, et al.* teach a vibration sensing method operated by a spontaneously generated power source and an apparatus therefor. The *Ishida, et al.* apparatus contains a piezoelectric power generating means using a piezoelectric ceramic which is subjected to vibration for causing a charge to be generated. The charge is converted into DC power by a DC conversion means and the DC power is applied to the level discriminating means and display means to sense and display the vibration.

There is a need in the art, however, for an apparatus which has essentially unlimited shelf and duty lifetimes and which can be fabricated as a monolithic device with the capability of being arrayed on a single chip to increase the power output. Therefore, there remains room in the art for a sustained power generator or alternate energy source which can overcome the shortcomings of the art.

SUMMARY OF THE INVENTION

It is, thus, an object of the present invention to provide a sustained power generator capable of being arrayed on a single chip.

It is also an object of this invention to provide a sustained power generator which is sized such that the size and costs of circuits may be reduced.

It is another object of this invention to provide a sustained power generator which has infinite shelf and duty lifetimes.

It is a further object of the present invention to provide a sustained power generator for use in low-power electronic devices.

It is an even further object of the present invention to provide a sustained power generator which can be manufactured as part of an integrated circuit, and utilized as a built in generator.

It is an even further object of the present invention to provide a sustained power generator having a plurality of cantilevers covering a broad range of resonant frequencies housed on a single substrate for manufacturing and user simplification.

These and other objects are achieved by a sustained power generator comprising at least one micro-fabricated suspended mass and a piezoelectric material in communication with each suspended mass, wherein a vibration of the mass causes stresses in the piezoelectric material, thus generating a current. These objects are also achieved by a method for providing a sustained power generator comprising the steps of providing at least one micro-fabricated cantilever means, the cantilever means having a free end and a secured end; placing a piezoelectric material in communication with each secured end of the cantilever; providing an external force for vibrating the free end such that a current is generated in the material in response to the external force vibrating the free end; and, providing a storage device in communication with the material for storing the generated current.

BRIEF DESCRIPTION OF THE DRAWING

The Figure is a schematic of the system of the present invention based on a micro-fabricated cantilever.

DETAILED DESCRIPTION

In accordance with the present invention, a novel and useful sustained power generator is described. Further description will be given with reference to the drawing. **The Figure** is a schematic representation of the preferred embodiment of the generator **1** (i.e., micro-generator) of the present invention based on a micro-fabricated cantilever. As shown in **The Figure**, the apparatus **1** comprises a suspended mass **10**, which in the preferred embodiment is a cantilever. The cantilever **10** has a suspended end **60** and a secured end **70** which is integral with the cantilever base **30**. The secured end **70** of the cantilever **10** is in communication with a material **20** which is preferably a piezoelectric material. As external forces are applied to the cantilever **10**, vibration is produced in the suspended end **60** which, in turn, causes the piezoelectric material **20** to produce an electric potential or a current. The current produced may be processed in a rectification means **40** and stored in a storage means **50**. The rectification means **40**, however, is an optional feature of the generator **1**.

In an alternate embodiment (*not shown*) of the present invention, the generator **1** is fabricated using multiple cantilevers **10** on a single substrate. In this embodiment, prior knowledge of the potential vibratory exposure is not required. The multiplicity of cantilevers **10** provides a means for covering abroad range of frequencies such that, when placed in an environment, only those cantilevers that resonate with the frequencies present will provide power, while the others will remain idle.

In this alternate embodiment, the manufacture would not waste resources fabricating large amounts of generators **1** to cover every conceivable energy or resonance range. Additionally, the user would not need to stock numerous devices functioning only in a narrow, predetermined energy band. Thus, a single generator comprised of a multiplicity of cantilevers **10** could be used in numerous situations, and would be self-optimizing in a dynamic environment.

The suspended mass or cantilever **10** of the present invention may take various forms, including any sort of suspended mass with the piezoelectric material **20** placed on the region of greatest vibrational stress. Other transducer elements such as a magnetic coupling could also be used. Additionally, the suspended mass **10** may be coated and/or implanted on a monolithic structure to greatly simplify its manufacture.

The generator **1** of the present invention may be fabricated using standard silicon-based micro-machining and coating techniques, resulting in a very small generator. The generator **1** may be manufactured as a part of an integrated circuit that could be energized by its own built-in generator. Of course, external vibrations from walking, driving, sound, machinery, air, fluid motion or other similar sources would be necessary to supply the mechanical energy to vibrate the suspended mass **10**.

The suspended mass **10**, in a preferred embodiment of the present invention, is designed to maximize the coupling to the anticipated external motion. The resonant frequency relation for a simple harmonic oscillator is $\omega^2 = K / M$, where K is the spring constant and M is the effective mass. The mass and spring constant are chosen as a result of the property of the material used to make the suspended mass **10**, and as a result of the mass **10** geometry, such that the resonant frequency and bandwidth correspond to a spectral region where the external vibration has significant power. For instance, in an instrument that is carried by personnel, the maximum spectral power occurs at low frequency, i.e., less than a few hundred Hertz, and, thus, the resonant frequency of the generator would be chosen accordingly. The generator **1** could also be designed so that its resonance width covers as much of the excitation spectrum as possible by providing a plurality of cantilevers **10** covering a broad range of the spectrum.

There is a limit to the amount of energy that may be produced by a micro-generator type generator **1** as described in the present invention. Specifically, the energy produced is

limited by the amount of excitation available from the environment. The total energy in a vibrating mass is $M\omega^2A^2/2 = KA^2/2$, where A is the amplitude of the vibration.

For example, with K=200 N/m and A=10 μm (or 10 micrometers), the energy produced is only one picojoule, or about a million times smaller than that consumed in a typical electronic wrist watch each second. Obviously, this is too small to power conventional circuits, but this configuration would certainly be suitable as a vibration sensor.

Larger spring constants coupled to larger masses may supply adequate power for conventional power circuits, such as the electronic wrist watch. For example, a 1-mg mass oscillating at 1400 Hz at an amplitude of 100 μm has an energy of one microjoule, enough for a wrist watch if the vibration is sustained.

The following table shows a variety of generators **1** and the energies they produce:

Mass (μg)	Frequency (Hz)	K(N/m)	Amplitude (μm)	Energy(J)
1000	226	2.0	1000	1×10^{-6}
1000	2300	208.6	100	1×10^{-6}
100	7150	201.7	100	1×10^{-6}
10	23000	246.5	10	1×10^{-8}
1	71500	201.6	1	1×10^{-10}
0.1	100000	39.4	1	2×10^{-11}
0.01	320000	40.4	1	2×10^{-11}

The masses shown are compatible with microlithographic fabrication. (A 1000-μg mass is about 1 mm^3 in silicon.) Obviously, devices with larger spring constants can store greater energies. The lower frequencies are compatible with vibrations produced by walking motions while the higher frequencies would generally be produced by high speed machinery or turbulent flow.

In an alternate embodiment of the invention, the generator **1** may be designed to act as an accelerometer sensor giving an output in the presence of motion or vibration, such as a fan or motor. In this alternate embodiment, the signal coming directly from the piezoelectric could be used and a simple amplitude convertor would provide an indication of activity.

The current or electric potential generated in the piezoelectric material **20** as a result of the intentional or incidental vibration of the suspended mass **10** is alternating current. The alternating current may be rectified in the rectification means **40**, if desired, and stored in a storage means **50**, such as a small battery, a capacitor, or some similar storage device. The storage means **40** should be convenient to use, must not be bulky, and must have some indefinite shelf capability and/or duty lifetime. The stored power may be utilized later to power a low-power electronic device, or some similar apparatus.

The present invention eliminates the need for batteries, solar panels, or attached wiring to power small electronic devices. The generator **1** of the present invention has an essentially indefinite shelf and duty lifetime. It can be fabricated as a monolithic device with the

capability of being arrayed on a single chip to increase the power output. The arrayed configuration can provide for responsiveness to a broader spectrum of mechanical frequencies, and the use of redundant converters in parallel would increase the power output. As such, the generator 1 can directly power an on-chip circuit so that completely monolithic integrated circuits can be envisioned. Consequently, the size and cost of such circuits could be greatly reduced.

A primary application of the present invention is for powering electronic devices, such as micro-sensors which may be carried in vibrating or jostling environments. Other examples include automotive and aircraft sensors where the motor vibrations and noise could provide the stimulation, where monitors are carried by active personnel, and in industrial-process monitoring environments where external electrical power would be inconvenient to apply.

It will be readily understood by those persons skilled in the art that the present invention is susceptible of broad utility and application. Many embodiments and adaptations of the present invention, other than those described, and many variations, modifications and equivalent arrangements will be apparent from or reasonably suggested by the present invention and foregoing description thereof, without departing from the substance or scope of the present invention as defined by the appended claims.

WE CLAIM:

1. A sustained power generator comprising:

at least one micro-fabricated suspended mass having a first end and a second end; and,

a piezoelectric-type material in communication with said second end of said at least one suspended mass;

whereby a vibration of said first end any said at least one suspended mass causes stresses in said piezoelectric-type material at said second end of said at least one suspended mass, thus generating a current.

2. The sustained power generator according to claim 1, wherein said at least one suspended mass comprises a silicon-based material.

3. The sustained power generator according to claim 1, wherein said at least one suspended mass is micro-machined.

4. The sustained power generator according to claim 1, wherein said at least one suspended mass is a coated cantilever.

5. The sustained power generator according to claim 1, wherein said piezoelectric-type material is in communication with an integrated circuit.

6. The sustained power generator according to claim 1, wherein said piezoelectric-type material is a film.

7. The sustained power generator according to claim 1, wherein a movement of said first end of any said at least one suspended mass cause stresses in said piezoelectric material resulting in an electric current.

8. The sustained power generator according to claim 7, wherein said electric current is alternating current.

9. A sustained power generator comprising:

at least one micro-fabricated suspended mass having a secured end and a suspended end, said suspended end vibratable in response to an external acceleration; and,

a piezoelectric material in communication with said secured end, said material generating a current in response to a vibration in said suspended end.

10. A sustained power generator comprising:

a plurality of micro-fabricated cantilevers, said plurality responsive to varying ranges of vibratory frequencies;

a piezoelectric material in communication with each said plurality of cantilevers, said material generating a current in response to a vibration in any of said plurality of cantilevers; and,

a storage device in communication with said material for storing said generated current;

wherein, a portion of said plurality of cantilevers responsive to particular vibratory frequencies respond by vibrating, while another portion of said plurality of cantilevers which are not responsive to the particular vibratory frequencies remain idle.

11. A method for providing a sustained power generator comprising the steps of:

providing at least one micro-fabricated cantilever means, said at least one cantilever means having a free end and a secured end;

placing a piezoelectric material in communication with said secured end of said at least one cantilever;

providing an external acceleration for vibrating said free end such that a current is generated in said material in response to said external force vibrating said free end; and,

providing a storage device in communication with said material for storing said generated current.

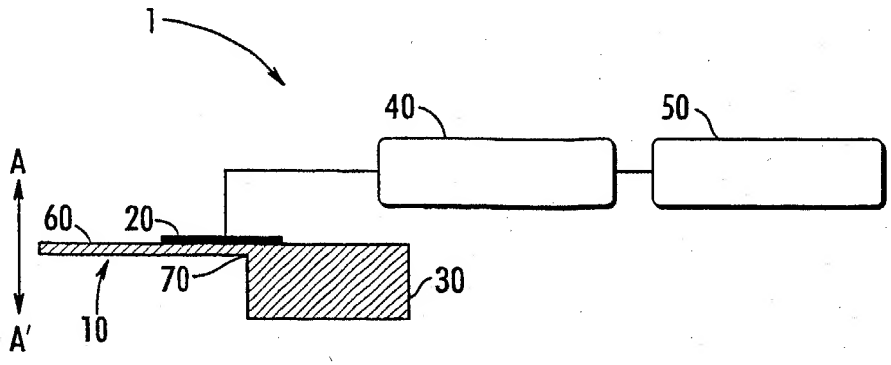


FIG. 1

INTERNATIONAL SEARCH REPORT

Intern. nal Application No
PCT/US 00/25355

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H02N2/18 H01L41/113

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01L H02N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
INSPEC, EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	GB 2 326 275 A (DAEWOO ELECTRONICS CO LTD) 16 December 1998 (1998-12-16) page 4, line 1 -page 21, line 6; figures 5,11	1-9,11 10
A	PATENT ABSTRACTS OF JAPAN vol. 1996, no. 12, 26 December 1996 (1996-12-26) & JP 08 205273 A (MITSUBISHI ELECTRIC CORP), 9 August 1996 (1996-08-09) abstract -& JP 08 205273 A (MITSUBISHI ELECTRIC CORP) 9 August 1996 (1996-08-09) paragraph '0027! - paragraph '0030! paragraph '0046! - paragraph '0048! figures 1,2,10	1-11

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
7 December 2000	14/12/2000
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk	Authorized officer

INTERNATIONAL SEARCH REPORT

Information on patent family members

Intern. nal Application No
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB 2326275 A	16-12-1998	NONE	
JP 08205273 A	09-08-1996	NONE	